Understanding Batteries and Chargers for RC Sailing

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Introduction

A working knowledge of the theory of sailing, and Racing Rules of Sailing is not a prerequisite for entry to the growing sport of radio-controlled sailing, but it helps. Neither is there a need to have in-depth knowledge of the technical issues associated with radio control and in particular on-board servos, and the power supplies required to drive them. However as the beginner's skill levels develop so also will their interest in how radio control works.

So, this paper has been written to help provide some of that knowledge and to hopefully clarify the confusion among some RC sailors.

The paper introduces simple electric circuits, batteries and chargers. Some of the material may be seen to be irrelevant or perhaps incomprehensible so a simpler introduction has been provided in a companion paper *"An Introduction to Batteries and Chargers for RC Sailing".* This is for those new to the sport and who have only limited technical knowledge and do not wish to develop that further.

Both papers have a DF65/95 Australia bias but hopefully will have world-wide applicability. Feedback would be very welcome. See contact details at end of this paper.

Additionally, reference is made to a separate paper *"Set-up of FlySky FS-i6 Transmitter (Tx) and FS-iA6B Receiver (Rx)."*

Electricity can be dangerous and an electric shock from faulty domestic wiring or appliances can kill - particularly around water. At low voltages of the magnitude encountered in RC sailing this is most unlikely, but the incorrect use and disposal of batteries can cause excessive heating and fire, so care is required, and manufacturer's advice should be followed.

DC Circuits

1. Lightning aside, electricity had its earliest manifestation in the form of a static electric charge obtained when cat's fur, or silk cloth was rubbed on a glass stick. A static charge is built up. We experience this phenomenon when we walk on a lush carpet and our body acquires an electric charge. When we touch a metal object such as a door handle the charge is dissipated and we experience this in the form of a spark and a mild electric shock.

2. The unit of measure of charge is the Coulomb. The charge generated from rubbing materials together, as described above, is typically only a few micro coulombs. The charge is analogous to the size of a dam in a hydro-electric system i.e., the volume of water stored in the dam. We measure a battery capacity in ampere hours (Ah).

3. Since an amp is defined as one coulomb per second, we can check the dimensions as follows:

> Battery capacity in amp-hours = amps x hours = Coulomb per sec x hours = Coulombs ($CT^{-1}T$). A full explanation of *Dimensions* can be found here: https://en.wikipedia.org/wiki/Dimensional_analysis

4. The electric charge is considered useful when we create a means for that charge to flow in a circuit and do work. The work done is often in the form of heating, lighting or conversion to a magnetic field. This happens when we have a more permanent source of

electrical energy such as a battery, solar panel, generator etc., a circuit of conductors and insulators, and a load such as resistor/s, an electric motor, servomechanism etc.
5. The moving charge, in the form of electrons moving around an electric circuit, is called electric current. In many ways it is not dissimilar to the movement of water in a hose and just as water flow can be measured as a rate in litres per minute, current is measured in coulomb per second where one coulomb is a charge equivalent to 6.24×10^{18} electrons. Current is measured in amperes or amps.
6. The source of energy that creates this flow of electrons may be a battery or power pack of the type used to charge a phone or an enormous 1,000MW alternator. The "pressure" generated, that which causes the current to flow, is sometime called the potential or potential difference or emf (electro motive force), or more commonly the voltage. It's analogous to the pressure in a garden hose. Just as increased pressure (the head) will cause more water to flow, a higher voltage power source will cause more current to flow. This relationship is given by Ohm's Law of which more below.
7. The current that flows in one direction from the energy source is called Direct Current or DC. Alternatively, in response to an alternating voltage, the current may alternate back and forth as alternating current or AC. In households this happens at 50-60 cycles per second (50-60 Hertz or Hz). Standalone batteries produce DC and all circuitry in RC sailing applications is DC.
8. An important battery characteristic is its capacity. Just as the volume of a dam (not its height) is a measure of its capacity, when connected to penstocks we become interested in how long that volume will last i.e., how long to empty the dam. So also, with a battery.
9. We measure capacity in ampere hours, and this is shown as Ah (sometimes milli amp hours - mAh). It is a measure under a given load of how long the battery will last before fully discharged.

Ohm's Law

Ohm's Law provides a simple relationship between the three fundamental parameters in DC circuits. It is:

> V=IR where voltage V is measured in volts, I is the current in amps and R is the resistance in ohms.

Thus, as voltage increases in a fixed circuit so does current. They are directly proportional.
Additionally, we can introduce power using these relationships:

> P=VI and using Ohms law (V=IR)
> $P= I^2R$ where P is power in watts.

Battery

1. A battery (sometimes called an accumulator) is essentially a storage device. Using a charger, it takes electric energy, usually from mains, and stores this in the form of chemical energy for later discharge as electrical energy.
2. A battery or battery pack is a collection of cells wired together, with housing, electrical connections, and possibly electronics for control and protection.
3. The fundamental unit is a voltaic cell, and a battery may comprise one or more cells connected in series or in parallel or both.
4/ Each cell comprises an anode, cathode and electrolyte. Convention has it that the anode is positive, cathode negative and current flows from the anode. The electrolyte may be either solid, a paste or liquid.
5. Cells are classified depending on whether they are rechargeable or not and are termed either a primary cell or a secondary (rechargeable) cell.

6. The discussion below is mainly restricted to the recommended batteries used in RC sailing and in particular the DF65 and DF95.

Cell Combinations

1. Only cells with identical nameplates should be connected to one another and this is done to either increase output voltage or output capacity, or both. They may be connected in series, in parallel, or a combination of both.
2. If connected in series (as in a car battery) the output voltage is the sum of the voltage of the individual cells. Perhaps counter intuitively, the capacity remains the capacity of an individual cell. If connected in parallel however the output voltage remains unaltered, but the capacity is additive.
3. The ONBO LiFe battery often used in the FlySky receiver is rated 6.6v and comprises two cells in series and this is shown on the battery as 2S.

Primary Cells

1. The most common primary cells are labelled Alkaline which come in the following popular sizes AAA, AA, C, and D each with a rated voltage of 1.5 volts. They are used mainly in low power applications in portable devices that have a low current drain and are used intermittently.
2. The popular FlySky onboard receiver requires a power source in the range 4.0-6.5V DC. While four 1.5V alkaline cells (AA) can be used most serious sailors prefer a rechargeable battery such as LiFe (LiFePO4) 6.6 v 2S 850 mAh as a more sustainable and lower cost alternative. More of this battery below.
3. Primary cells cannot be reliably charged, and manufacturers recommend this not be attempted as rupture and leaking of hazardous liquids may result. As with all batteries they should be disposed of in the recommended way.

Secondary Cells

1. Batteries comprising secondary cells are rechargeable and may not have a full charge when supplied. They are recharged by a charger by applying an electric current to the anode and cathode terminals which reverses the chemical reaction that occurs when discharging.
2. The best-known rechargeable battery is the lead-acid battery widely used in automobile and boating applications.

A Guide to Understanding Battery Specifications

These two references provide excellent additional information on batteries

- MIT Guide to battery basics http://web.mit.edu/evt/summary_battery_specifications.pdf)
- Electropaedia https://www.mpoweruk.com/performance.htm

What the Numbers Mean

Most batteries will be labelled with the following numbers:
Voltage in volts (v) e.g., 6.6 v
Capacity: amp-hours or usually shown in milli amp-hours (mAh) e.g., 850 mAh
C-Rate: A charge rate multiplier shown as nC e.g., 25C
There may be other numbers that relate to battery physical size and shape.

Battery Types and Sizes

A comprehensive list of battery types and sizes is provided at
https://en.wikipedia.org/wiki/List_of_battery_sizes

Li-ion Batteries (not to be confused with LiFe)

1. These are a large group of rechargeable batteries that include LiFe and LiPo batteries. All are based on the use of a lithium compound as the cathode such as lithium ferrite phosphate (LiFePO4, sometimes shortened to LiFe or LFP, and lithium-ion polymer (LiPo). They have a wide range of applications from portable devices (e.g., iPhones and Laptops to power tools to electric vehicles).
2. The Wikipedia reference (https://en.wikipedia.org/wiki/Lithium-ion_battery) lists twelve different types in the Li-ion family.

Battery Capacity

1. A battery's capacity is a measure of the amount of electrical energy that it can store and safely discharge but does not indicate the rate this energy transfer can take place. See C-Rate below.
2. Capacity is a function of the chemical energy stored which in turn is determined by the physical battery size, the chemical properties of anode, cathode and electrolyte, its thermal characteristics i.e., internal resistance and its ability to disperse heat, its state of discharge and its age - counted in number of cycles.
3. Capacity is measured in ampere-hours and in RC applications is usually shown as mAh (milli amp hours). It is the product of the discharge current, I (amps) and the discharge time t, at a given load, and is expressed in amp-hours or milli amp hours (mAh).
4. The capacity may also be shown in real energy terms such as watts or milli watts hours (mWh). This is a superior measure as it reflects the cell's nominal voltage because W=V***I**.
5. A battery rated 1 Ah could theoretically store and deliver 1 amp for one hour, or 0.5 amp for 2 hours or 2 amp for 0.5 hours or any of a number of other multiples.
6. Capacity measured in (Ah) is only approximate and in some instances misleading because whilst 1Ah cell could probably deliver 1mA for 1,000 hours (0.001 x 1,000 = 1,000 mAh) it certainly could not deliver 100 amps for 0.01 hours (36 seconds). The heat generated by 100 amps would probably cause a fire.

7 The current delivered by a battery in use is determined by its voltage and the connected load, see Ohms Law.

8. Given that battery capacity is measured in amp-hours, this is equivalent to coulomb per second x hours. Thus the dimensions are CT^{-1} x T or C (coulombs). This capacity measure does not reflect the time rate at which the charge can be taken up or be delivered, so manufacturers introduced the concept of the C-Rate, but this is neither a measure of Charge Rate nor Coulomb Rate nor Current Rate but rather it is a multiplier, the reciprocal of which is the charge/discharge time. This will become clearer when we examine C-Rate below.
9. There is no known National or International Standard for measuring battery capacity.

C-Rate

1. According to this MIT[1] reference: *"C-Rate is a measure of the rate at which a battery is discharged relative to its maximum capacity*", where capacity is measured in Ah. Other

[1]MIT - Massachusetts Institute of Technology

references define C-Rate as the *maximum* rate at which a battery is charged/discharged relative to its maximum capacity.

2. C-Rate is normally shown as nC where n has the dimension of 1/t or T^{-1} i.e., per unit time. When C-Rate is shown in this way n is a multiplier and 'C' only means n is the C-Rate multiplier.

Thus, from the above definition

C-Rate = I_{max}/ Cap, where Cap is the rated capacity in Ah.

3. Using the 6.6 v ONBO 850 mAh battery with a C-Rate of 25C as an example, under ideal conditions, the battery could be charged or discharged at a maximum current of I_{Max} where, using the above definition and after transposing,

I_{max} = C-Rate x Cap (Ah)
= 0.85 x 25
= 21.25 amps

Also, since

Cap = amp (I) x hours (t) then
t = Cap / amp (I)
= 0.85 / 21.25
= 0.4 hrs
= 2.4 min

4. The label on batteries can show a C-Rate from 0.2C to 100C. If not specified on the battery or in data sheets a rate of 1C is normally assumed. 1C means that theoretically the battery can be charged/discharged in 1 hour.

C-Rate In Perspective

1. Since the C-Rate is a measure of the rate at which a battery can be charged and discharged, a large C-Rate suggests the battery can be *charged* at a high rate (i.e., a large current for a short charge time) and equally *discharge* a large current for a short period of time. Such batteries are said to be suitable for high impact loads, such as starting an automobile or operating the shutter release of a DSLR camera.

2. The need to apply a fast charge is most apparent with electric automobiles (EVs) such as the Tesla. Here a high C-Rate battery is required to accept a very fast charge particularly at a country service station. This is seen to be just as important as the vehicle range (km). The Tesla company suggests that very high charge rates should be avoided and that charging faster than about C/2 (two hour charge) can reduce the cell's life". Other references claim the Tesla battery to have a C-Rate of only up to 4C. See here. Incidentally, Porsche claims to have achieved an 85% charge within 20 minutes.

3. Battery University (https://batteryuniversity.com/article/bu-402-what-is-c-rate) says "*Some high-performance batteries can be charged and discharged above 1C with moderate stress*" suggesting 1C or less is more appropriate to preserve battery life.

4. The value of the C-Rate is a measure assigned by the battery manufacturer and there appears to be no National or International Standard by which C-Rate is or should be measured. Hence whilst a large C-rate is seen to be a desirable battery attribute it is not necessarily a reliable guide to battery performance.

5. The physical size of the familiar ONBO 850 mAh battery is about that of a matchbox. A C-Rate of 25C appears to be grossly exaggerated in that if charged or discharged at a rate of 21 amps for over 2 minutes (see calculation above) it would cook very quickly, probably ignite and trip the household circuit breaker. To get this current in perspective, a domestic 240v 800W bar radiator (electric fire) would draw about 3 amps.

6. When all is said and done, when a battery is in use, the actual charge current is determined by the charger characteristics and in particular the charger settings. For a

given voltage, the discharge current is determined by the load and the internal resistance of the battery.
7. The reassuring fact is that both of the commonly used batteries given in this paper are perfectly capable of meeting the imposed DF65/95 loads for many hours - provided the battery is cared for, fully charged at the start and recharged before every outing. It is stressed that the C-Rates given for both of these batteries are very different, but both do the job.
8. A LiFe battery can be permanently damage if discharged below a critical voltage. If using the FlySky-i6 Transmitter/Receiver combination, the user is advised to set the receiver battery alarm voltage to 5.2v and to prevent battery under-volt damage the battery disconnect voltage should be set to 4.9v.
9. The literature abounds in C-Rate confusion probably because many of the references have been written by the marketing departments of the battery manufacturers or enthusiastic model airplane users. It may also arise as a result by poor translation. I hope the foregoing doesn't add to the confusion!
10. So it would seem that C-Rate is irrelevant for RC sailing applications but for the sake of completeness, we compare these two commonly used batteries to make this point:

Given C-Rate = Imax (milliamps)/Capacity (Cap in mAh)

	ONBO	Zippy
Rated capacity in mAh	850	700
Manufacturer's C-Rate	25	5
Maximum Charge/Discharge current = Ah x C-Rate	= 0.850 Ah x 25 = 21.25 amps	= 0.700 x 5 = 3.5 amps
Hours(t) to charge/discharge at maximum rate =Cap(mAh) / rated discharge current	t = Cap (Ah)/ I_{Max} = 0.850/21.25 = 2.4 min.	t = 0.700/3.5 = 12 min.

Chargers and Charging

1. After discharge, all batteries comprising secondary cell/s require a battery charger to restore the battery to a fully charged state.
2. The individual cells in a battery pack vary and there may be small differences in their capacity and so, over time may have a different state of charge (SOC). These variations in capacity are due to manufacturing variances, assembly variances (e.g., cells from one production run mixed with others), cell aging, and impurities.
3. The popular FlySky receiver battery has two cells in series. Balancing these during charging helps to maximise capacity and service life of the pack by maintaining the state-of-charge in each cell. Balancing is only necessary for packs that contain more than one cell in series. Parallel cells will naturally balance since they are directly connected to each other, but groups of parallel wired cells, wired in series (parallel-series wiring) must be balanced between cell groups.
4. The recommended chargers below give a balanced charge if set up correctly.

Self-Discharge

There are ongoing internal chemical reactions in any cell, and these reduce the stored charge and thus decrease the capacity of the battery over time. This phenomenon is called self-discharge.

The battery shelf life is defined as the longest time a battery can be stored before its capacity falls below 80% of its nominal capacity.

Battery Memory
Battery memory describes the situation in which NiCd batteries gradually lose their maximum energy capacity if they are repeatedly recharged after being only partially discharged. The battery appears to "remember" the smaller capacity. A good charger should automatically fully discharge the battery before the charging process starts.

Battery Nomenclature
See this Wikipedia reference for primary and secondary battery nomenclature:
https://en.wikipedia.org/wiki/Battery_nomenclature

Shipment of Battery Packs
A more detailed explanation of the limitations on shipment and transportation of batteries is given at this reference: epec //custom battery packs

Available Battery Chargers
1. The charger will usually include a) a power supply to transform 240v AC to the charger nominal output AC voltage, b) a rectifier and smoothing filters to convert AC to DC and c) a battery management system (BMS) to measure battery state and provide the optimum charging current and voltage at the battery terminal for the time required. If the cells are arranged in series the charger will provide additional cabling to monitor the state of individual cells and provide a balanced charge.
2. Each battery type and size has a particular set of constraints and requires specific charging regimes. For example, NiCd batteries should be nearly completely discharged before charging and this may be provided by the battery management system. See also Battery Memory. Typically a battery charger designed for one battery type cannot be used for another type. The chargers recommended below can be set up to charge different battery types.

Optimum Charge Rate
Depending on the charger, the user will be invited to set the charge rate, often in amps. Overall, slow charging is deemed to be better because the thermal heat build-up is less. Temperature extremes, hot or cold, are never good for batteries. Also there is a lower risk of over-charging which can reduce battery cycle life. So, if you have a choice use the lowest current setting – after all you have plenty of time. The literature also suggests a fast charge rate may result in a lower charge.

Transmitter/Receiver Combinations for DF65 and DF95

1. By far the most commonly used transmitter/receiver combinations used world-wide and recommended by the DF65/95 manufacturer Joysway is the Joysway J4C05 or the FlySky FS-i6. The former is the default system in UK and Australia, and both are available from the North America supplier.
2. The FlySky system provides more advanced functions and is favoured by serious sailors. Alternatives are available, including Spektrum and Radiomaster but what follows will be restricted to the Joysway and FlySky brands. Both require the same batteries.
3. The type and size of battery required for the transmitter (Tx) is determined by the transmitter voltage, the load and the housing provided to accommodate the battery.

Because the receiver requirements are different to the transmitter, a different battery is required. Equally because the batteries are different the chargers are different.

Battery Requirements for FlySky FS-i6 and Joysway J4C05 Transmitters:
Either a) four 1.5v AA Alkaline cells, or preferably b) Rechargeable cells, say four 1.2v NiMH (Nickel Metal Hydride) AA cells or four 1.5v Li/FeS2 (Lithium Iron/Disulfide) AA cells. Both transmitters provide a housing to accept four AA cells.

Battery Requirements for FlySky or Joysway Receivers
Either a) four 1.5v AA cells mounted on a snap-in tray under main hatch, or preferably, b) a single 2S 6.6v battery similar to ONBO 850mAh (a Hobby King look-alike is available) or Zippy 700mAh or similar, mounted with Velcro on the keel box inside the hull and accessed from the forward hatch. An extension lead will be required for this recommended option. Also, with this arrangement the main hatch can be left in place between outings.

Transmitter: Panasonic BQ-CC51 Battery Charger:
The Panasonic shown here accepts 4 x 1.2v NiMH cells. There are three flat pins on the back to allow it to be plugged directly into a 240v AC outlet. Green LEDs glow when charged. A number of other brands are available.
Features: Very simple to use and provides a constant current charge. Some brands provide capability to charge both AA and AAA cells at the one time.
Price: AUD 50
Available from: Various sources. Search using “NiMH charger”

Warning

Before purchase, always check the power supply of charger is compatible with your domestic power supply, suitable for the battery you wish to charge and all cables including the black JS/Futaba battery connectors are provided.

Receiver: SKYRC e430 Battery Charger

Features: Accepts 2, 3 and 4 cells for balanced charging of LiFe and LiPo cells. Very simple to use but very limited functionality. Does not accept AA batteries.
Price: AUD 29 and includes 240v power supply
Available from: Banggood, eBay and HWS (Aus.) but may no longer be stocked. B6 mini shown below is favoured.
Link to manufacturer site:
https:https://www.skyrc.com/Charger/e430_Charger
Link to site for manual:
https://www.manualslib.com/manual/1386587/Skyrc-E430.html

Receiver: SKYRC iMax B6 mini Battery Charger

Features: Accepts 2, 3 and 4 cells for balanced charging for a range of secondary batteries including LiFe, LiPo, NiCd and NiMH. This is an upgraded version of the well-known IMAX B6 and is claimed to be more accurate and stable and has new automatic charging features. Refer manual. Does not accept AA batteries
Approximate Price: AUD 45, Power supply AUD 23
Available from: Banggood, Hobby Warehouse
Link to manufacturer site: https //www.skyrc.com/iMAX_B6mini_Charger
Link to manual:

https://www.manualslib.com/manual/889362/Skyrc-Imax-B6-Mini.html
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Receiver: G.T Power Battery Charger

Features from site: Accepts 2, 3 and 4 cells for balanced charging, auto detection of current rate and capacity of individual cells, identifying cell count automatically, automatic cut-off for safety temperature protection function and adjusts the charge power automatically when overheating. Does not accept AA batteries
Price: USD 39.95
Available from: www.radiosailing.net
Link to distributor site: https://radiosailing.net/collections/batteries-chargers/products/2-4-cell-ac-dc-dual-lipo-life-battery-balance-charger

Link to manual: Not found

Multimeter
Multimeters are available from electronics stores such as Jaycar (Australia) and hardware chains (Bunnings) or online. A multimeter is an invaluable tool for fault finding particularly the following conditions and most modern digital types can show negative voltage and thus are suitable for checking polarity:

- battery voltage condition: select V (DC)
- open circuit by selecting resistance (ohms or Ω): should show very large reading
- short circuit by selecting resistance (ohms or `Ω): should show zero reading
- polarity: should show negative value if wrong polarity

Current can only be measured by determining the voltage across a resistor of known value and applying Ohms Law or by inserting the multimeter into the circuit.
YouTube have a number of good sites. Search on “Use of multimeter”.

Disposal of Batteries
All unserviceable batteries should be held in a container (an empty PET bottle serves) and at infrequent intervals taken to a waste disposal agency or a battery retailer, such as Battery World, for safe disposal. Batteries in landfill are an environmental hazard.

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